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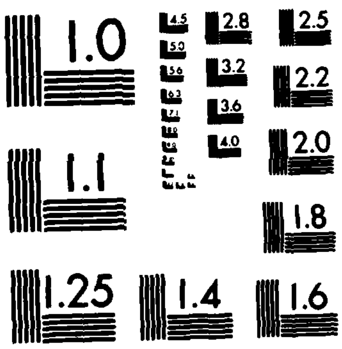

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An Introduction to Heat Tracing

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US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

CRREL's *Cold Regions Technical Digests* are aimed at communicating essential technical information in condensed form to researchers, engineers, technicians, public officials and others. They convey up-to-date knowledge concerning technical problems unique to cold regions. Attention is paid to the degree of detail necessary to meet the needs of the intended audience. References to background information are included for the specialist.

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Heat tracing is the generic term which refers to the application of heat to a pipeline or vessel to prevent freezing, to thaw frozen fluid, to maintain viscosity or temperature of a fluid, or for other reasons such as to keep components from separating or gas from condensing. The purpose of this digest is to summarize current heat tracing practices—their principles of operation, advantages and disadvantages. Heat tracing methods covered include heat transfer fluids (glycols and heat process fluids), steam, and electricity (resistance, skin effect, impedance and inductance).

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COLD REGIONS TECHNICAL DIGEST No. 86-1, JUNE 1986

USA Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

An introduction to heat tracing

Karen Henry

Introduction

Heat tracing is the generic term which refers to the application of heat to a pipeline or vessel to prevent freezing, to thaw frozen fluid, to maintain viscosity or temperature of a fluid, or for other reasons such as to keep components from separating or gas from condensing. The term originated with the placement of steam lines adjacent to process or transport lines—the transporting pipeline was "traced" with the steam line. Cold regions operations increase the demand for freeze prevention and viscosity maintenance. Freeze protection is especially important, since freezing can damage pipes and equipment.

Heat tracing can utilize the heat given off by a hot fluid line near or touching a pipeline. Or it can use the electrical resistance of materials to produce heat, either in the pipeline itself or in a cable or pipe which is in contact with or placed inside the pipeline.

The purpose of this digest is to familiarize the reader with current heat tracing practices, and to survey the heat tracing methods available. Each method is described, and its principles of operation, advantages and disadvantages are discussed.

The author, a civil engineer, is a member of CRREL's Civil Engineering Research Branch.

This digest is not meant to be a heat tracing design guide; it does not contain detailed calculations on heat transfer and economics. Appropriate design references are cited through-

out the report. A rough screening of the literature was conducted before the references were compiled, and a wide variation was noted in the quality of specific design guidance given. Apart from small-scale water freeze protection, each heat tracing system should be designed for its specific application. Many manufacturers have design capability and will provide the guidance needed.

Tables 1 and 2 (p. 10–12) list the temperature ranges of heat tracing methods and the advantages and disadvantages of each method. These tables may be used to find the most likely candidates for a specific application. The text can then be referred to for greater detail. Table 1 lists both the maximum fluid maintenance temperature for each heat tracing method and the highest temperature to which the system can be exposed without damaging it.

All heat tracing systems except steam are capable of close temperature control. Thermostats are usually used with freeze protection systems, and can be used with steam. A thermostat is an on-off controller with a temperature sensor. The power is activated when the ambient temperature falls below a set point.

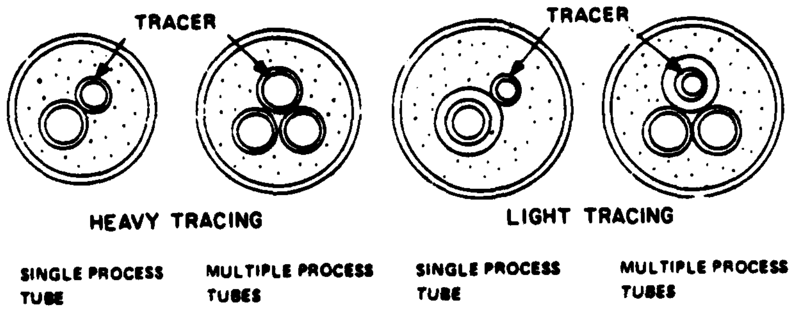
For close temperature control, there are sophisticated controls and temperature sensors available, such as analog control devices and thermistors or thermocouples. Analog controllers vary power input to a system as temperatures vary; they are usually reliable when installed properly. Because they moderate the power used for heat tracing, they are often greater energy-savers than thermostats. Even though analog controls are more expensive than thermostats, they are sometimes used with freeze-protection systems for reliability and economy. IEEE Standards 622-1979 and 622A-1984 cover the design and installation of electric pipe heating and control systems.

Heat tracing fluids

Steam has a high specific heat and a high latent heat of vaporization, making it an ideal fluid to carry and transfer heat. It is also universally available and nontoxic, and presents no danger of arcing in explosive environments.

Steam

Saturated steam is used for heat tracing. The heat is transferred to the medium being traced largely through condensation. Steam can be applied internally, externally, or as jacketing, where it completely surrounds the process or transport pipe (Kohli 1979, Schilling 1983).



1. Basic single tracer/pipe arrangements for heavy and light steam tracing (after Oehlschlaeger 1976).

Internal tracing and steam jacketing are expensive and complicated ways to use steam for heat tracing and are therefore rarely used. A pipe with internal steam lines is hard to clean, and both internal tracing and jacketing become complicated in the presence of valves or any other geometrical irregularities (Kohli 1979).

An external steam tracing system consists of headers, the supply line, traps, and usually a line to return the condensate to the source. Steam tracing is available at temperatures up to 370 °C (700 °F) but it is usually not used above 200 °C (400 °F) because of the high pressures involved (Luke and Miserlis 1977, Oehlschlaeger 1977).

The steam trace-line and product line are usually contained in an insulated bundle. They can be in direct contact, which is referred to as "heavy tracing," or they can be isolated by insulation, which is referred to as "softening," or "light tracing" (see Fig. 1). Softening makes steam use more efficient. The product pipe is a much greater heat sink than the surrounding insulation, and the contact with the pipe can be somewhat irregular. The insulation redistributes the heat more evenly along the line, and thus eliminates hot spots, allowing efficient steam use over long runs. When high heat loads are desirable, direct contact between the heat tracing and product pipe is most suitable. Heavy tracing is the easiest form of steam tracing to design and install (Luke and Miserlis 1977, Kohli 1979).

The most significant problem with steam tracing is an effect known as "tailing." As heat is given off to the fluid line and to the insulation, the steam condenses and its pressure drops; pressure is also lost to friction. The pressure loss along the line is accompanied by temperature reduction, or "tailing." This effect can be mitigated by wrapping the tracer around the fluid line, increasing the number of turns per unit

length as distance from the header increases. Accurate heat-transfer calculations and testing are necessary to determine the actual reduction in tailing accomplished (Schilling 1983).

Steam traps are also employed to expel condensate from the lines and thus reduce tailing. This helps reduce build-up of water film (which will lower the heat transfer characteristics of the trace-pipe wall) and maintains the desired steam flow rate. The use of steam traps, however, only reduces and does not eliminate the tailing effect (Oehlschlaeger 1977, Kohli 1979, Schilling 1983). In addition, steam traps are one of the most expensive maintenance items on a steam tracing system. They need to be repaired and replaced periodically to prevent malfunction or failure. It has been estimated that 25% of the heat energy of steam is lost at steam traps (Hammack and Kucklinca 1977), and unless the traps are self-draining or are manually drained, the condensate in them may freeze during a shut-down.

Saturated steam exists at unique combinations of temperature and pressure. If the pressure is reduced the steam becomes superheated, but the superheat in heat tracing applications is rapidly dissipated. For this reason, the basic control of steam heat tracing temperature is a pressure-reducing valve, and precise control of temperature is difficult to achieve with this method. In addition, uneven contact between the steam line and product pipe results in uneven distribution of heat. This effect becomes more significant if the steam temperature is quite different from the fluid maintenance temperature. Because of tailing, uneven distribution of heat, and the use of pressure reducing valves, temperatures of steam tracing methods typically will vary around a desired temperature by $\pm 5\frac{1}{2}$ °C (10°F) below ground or ± 11 °C (20°F) above ground (Clough 1984).

Steam jacketing can provide very close temperature control, but can only be used practically on short sections of pipeline.

Steam tracing is used primarily for freeze and pour-point protection. Steam is utilized most efficiently when the desired line temperature is close to that of steam at reasonable or available pressures.

Economic comparisons were found in the literature reviewed. Most of them show that steam is significantly more expensive to install and maintain than electrical resistance heat tapes, even though the energy cost is lower. This is be-

cause the control of energy input is greater with the electrical resistance heat tapes so the electrical systems use less total energy. Installation, maintenance and energy costs vary with location, and the two systems are comparable in some situations (Luke and Miserlis 1977). The economics become more favorable if the steam is a byproduct of a process already in place. Some expense may be involved in assuring the quality of the steam.

Several factors should be borne in mind when considering the use of steam tracing. If an electric power source is not available or reliable, steam tracing is the best option. Most temporary repairs can be made on steam tracing while the system is in operation, whereas most repairs on other heat tracing systems require system shutdown. Steam can provide many times the design heat loss for continuous operation to a line, thus providing melt-out in a very short time. Moisture and corrosion can affect some electrical systems, and some can't be used in explosive atmospheres. Steam tracing presents few problems in such environments, provided the system does not exceed the ignition temperature of vapors in the atmosphere. Finally, some maintenance personnel are more comfortable with steam tracing (mechanical) than with electric tracing with its electronic control systems.

Design and application of steam tracing systems are treated by Bertram et al. (1972), Oehlschlaeger (1976, 1977), Luke and Miserlis (1977), Kohli (1979) and Schilling (1983).

Other heat transfer fluids

Other heat transfer fluids can be divided into two categories: glycols and "heat process fluids." (Heat process fluids are also referred to as "high temperature organics" or "hot oils.") Both types of fluids are used for a variety of heat transfer purposes—heat tracing being only one. Heat process fluids are usually used for high temperature applications 150°–400°C (300°–750°F), and glycols are used at temperatures up to 120°C (250°F).

There is a scarcity of information available from users of heat transfer fluids for heat tracing. Most of the following discussion is based on Dow Chemical Company literature.

Heat tracing systems utilizing heat transfer fluids in the liquid phase can achieve as precise temperature control as necessary with proper design. Used in the liquid phase, they require only one steam trap (associated with the steam boiler used to heat the fluid) and therefore avoid the related equip-

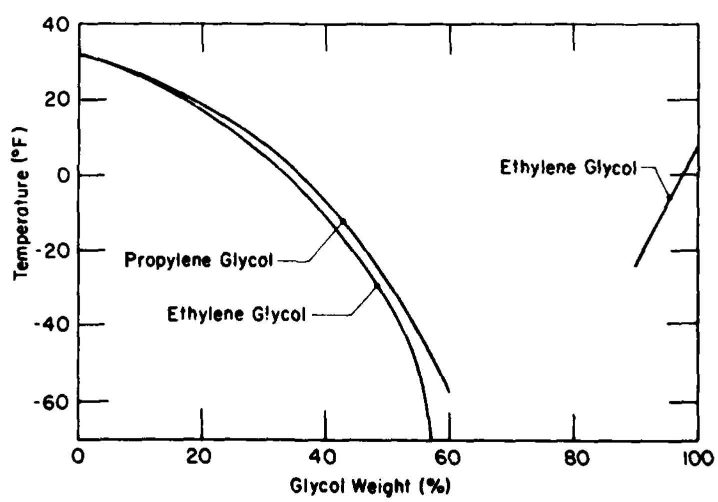
ment installation and maintenance cost. They do require special pumps and reservoirs, however, which add to the cost.

Glycols. There are two glycols commonly used for heat transfer: ethylene and propylene. The glycols manufactured for heat transfer have specially formulated corrosion inhibitors added. This, along with their properties as freezing point depressants when added to water, and their wide range of operating temperatures (-50°F to 250°F), make glycols attractive options for heat tracing.

Glycols are used in aqueous solutions ranging from 20% to 60% by weight, thus taking advantage of the specific heat of water to enhance their heat transfer characteristics. The trade-off for the lower freezing point obtained with glycol is a less efficient heat transfer (lower specific heat). The freezing point depressant characteristic is important because the system is then protected from freezing even during intermittent operation. Figure 2 is a graph of the freezing points of various aqueous glycol solutions.

Ethylene glycol at a concentration of 60% will remain liquid down to temperatures of -50°C (-58°F), whereas a 20% solution has a freezing point of -9°C (16°F). Propylene glycol remains liquid down to -33°C (-28°F) in higher concentrations. The upper temperature limit of glycol solutions used for heating is 120°C (250°F).

Glycol systems require periodic checks and replacement to ensure that the glycol concentration is at the necessary level. Glycols are hygroscopic and the corrosion inhibitors break down over time.



2. Freezing points of aqueous glycol solutions (redrawn from Dow Chemical Company literature).

Propylene glycol is considered safe for use in foods, whereas ethylene glycol is regarded as being too toxic for applications where there is a possibility of ingestion. For this reason, it is best that propylene glycol be used for heat tracing of potable water supplies unless double-walled heat exchangers are employed.

The Alaska Area Native Health Services have had good results with propylene glycol systems for freeze protection of water utilities in arctic installations. The glycol systems have a better service record than electric heat tapes, which are easily damaged during installation or become corroded (Farmwald 1984).

Some users have elected to retrofit steam systems with glycols because of lower maintenance costs and because steam traps often malfunction.

Heat Process Fluids. The term "heat process fluids" refers to a variety of special organic fluids developed for heat transfer at -70°C (-100°F) to 260°-400°C (500°-750°F). As mentioned previously, these fluids are most often used for heat transfer at temperatures above 150°C (300°F) and probably towards the upper end of the 260°-400°C temperature limitations. This is because they cost about three times as much as undiluted glycol.

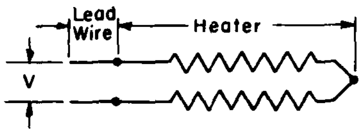
Heat process fluids can be used in the liquid phase or in the vapor phase. The fact that the vapor pressures of saturated heat process fluids are much lower than steam vapor pressure at the same temperature reduces the cost of equipment. For example, at 300°C (575°F) the pressure of saturated steam is 8590 kPa (1246 psi), whereas the vapor pressure of a heat process fluid manufactured by Dow Chemical at the same temperature is 882 kPa (128 psi) (Mrochek 1984).

Electrical resistance heat tracing

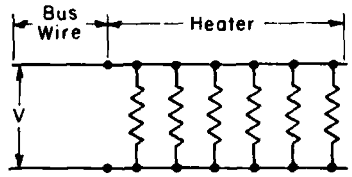
There are many forms of electric heat tracing. They can be divided into two categories: 1) electrical resistance heat tapes (or cables), whose mode of operation depends primarily on the electrical resistive properties of material when a current is applied, and 2) all other forms of electrical heat tracing, including skin effect tracing, impedance tracing and induction heating. In the second category, the methods take advantage of the magnetic inductive effects of an alternating current source.

Tapes and cables

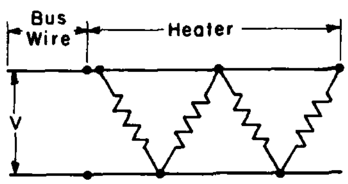
Electrical resistance heating cables or tapes are of two types: 1) those where the heating elements are connected in



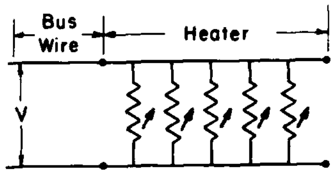
a. Series resistance.



b. Parallel resistance, continuous type.



c. Parallel resistance, zonal type.



d. Parallel resistance, continuous self-limiting type.

3. Circuit diagrams for resistance heat tracing (after Bylin and Hutzel 1979).

series (i.e. one continuous resistor), and 2) those where the heating elements are connected in parallel. Parallel resistance heat tracing has two or more heating elements connected across the voltage source. One type of parallel heat tape, called self-limiting (or parallel modulating), is capable of regulating its output locally along its length. Figure 3 shows circuit diagrams for various forms of electrical resistance heat tape.

Series Resistance Heat Tape. The most primitive forms of electric heat utilized series power cables and heaters which were adapted from other heating systems. Mineral-insulated copper-sheathed power cable would be overloaded with current, causing an I^2R heating effect* (Bilbro and Leavines 1969). Series resistance heating cables have a specific resistivity according to the user's specifications of length and required heat output. In most cases, a standard cable will be provided and a certain spiraling ratio recommended. For greater lengths, the manufacturer will produce a specific alloy of the correct resistivity.

The conductor used in series resistance cable is bigger in diameter than that used in parallel resistance heat tape; and (unlike parallel heating elements) it doesn't need to be connected to bus wires. These factors make series cable comparatively rugged and impact-resistant, as well as being capable of carrying high heating loads. Some series cables are made of

* I = current in amperes; R = resistance in ohms.

special alloys and insulated with magnesium oxide. They are referred to as "mineral-insulated" heat cable and can heat up to a temperature of 590°C (1100°F) (Lonsdale 1981, Fenster 1984).

Some disadvantages of series resistance heat tape are: 1) Any break results in complete loss of the circuit. 2) It is fairly stiff and unwieldy. 3) It requires skilled personnel for correct installation. 4) There is a risk of burn-out and fire if the tape is accidentally crossed over itself or subjected to local heating, or if poor contact is made with the process pipe which serves as a heat sink for sheath temperature.* 5) Magnesium oxide is quite hygroscopic, so that if mineral-insulated cable is exposed to moisture, the resulting corrosion can cause short-circuiting (Fenster 1984, Stewart 1977, Bylin and Hutzel 1979).

Temperature modulation of series resistance heat tape can be achieved during operation by varying the current made available to the circuit.

Parallel Resistance Heat Tape. Parallel resistance heat tape has heating elements which are electrically connected in parallel, either uniformly along a bus bar or in zones (see Fig. 3). Because the resistive elements are connected in parallel, the heat tapes can be manufactured at set wattages so they can be cut to length in the field, easily accommodating last-minute changes in the lengths required. Therefore, they are significantly less expensive to design and purchase than series heat tapes. The other major advantage in the use of parallel heat tapes is that if mechanical damage is incurred, only part of the heating circuit is lost.

The main disadvantage of the use of parallel heat tape stems from the resistive wires, which are thin and fragile. The thinner wires are also unable to carry high heating loads without melting, the upper temperature limits being 200°C (400°F). The connections between the heating elements and the bus wires are also easily damaged during installation and operation.

Continuous parallel heat tapes have more fragile connections between the bus wire and heating element than do zone heaters, making them more susceptible to mechanical damage. When a zone heater is damaged, however, more of the circuit is lost.

* The sheath of an electric cable is the outermost covering of the heat tracing cable.

Table 1. Temperature limitations of heat traci

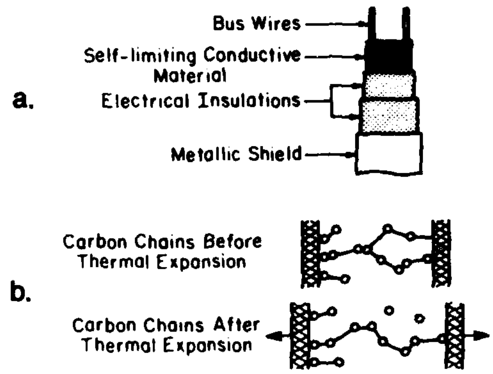
Heat tracing method	*Maximum fluid maintenance temperature*	*Maximum exposure temperature*	
A. Fluids			
1. Heat transfer fluids			
a. Glycols	150 °C (250 °F)	≈ 160 °C (325 °F)	See Figu glycols. tures, hi quired t sition.
b. Heat process fluids (organics)	260°–400 °C (500°–750 °F)	None	Most re temperat (−50° to mainten on the p used.
2. Steam	About 200 °C (400 °F); higher if the vapor pressure can be tolerated	None	This limi the vapo
B. Electricity			
1. Series resistance	590 °C (1100 °F)	Varies (see below)	Above 2 lated cal
2. Parallel resistance			
a. Continuous and zonal	PVC insulated: 65 °C (150 °F) Teflon insulated: 65 °C (150 °F) Silicone rubber insulated: ≈ 90 °C (200 °F)	220 °C (250 °F) 200 °C (400 °F) 150 °C (300 °F)	
b. Self-limiting	PVC insulated: 65 °C (150 °F) Teflon insulated: 150 °C (300 °F)	85 °C (185 °F) 190 °C (370 °F)	
3. Skin effect	≈ 150 °C (300 °F)	≈ 150 °C (300 °F)	Maximu limited t tor insul
4. Impedance	Up to melting point of metal being heated	None	Method above C loss of l
5. Inductance	Up to Curie point of metal being heated	None	This typ melt me molten

mperature limitations of heat tracing methods.

o	*Maximum exposure temperature*	*Comments*	*Source of information*
or th cu er	≈ 160 °C (325 °F)	See Figure 3 for freezing points of glycols. At high exposure temperatures, high circulation rates are required to prevent thermal decomposition.	Dow Chemical Co. literature
pu ol °F er la	None	Most remain pumpable down to temperatures of −45° to −70 °C (−50° to −100 °F). Maximum fluid maintenance temperature depends on the particular heat process fluid used.	Dow Chemical Co. literature
p the ssu	None	This limit is a practical one due to the vapor pressures involved.	Luke and Miserlis (1977)
(4 us	Varies (see below)	Above 200 °C (400 °F) mineral insulated cable is used.	Lonsdale (1981)
°C	220 °C (250 °F) 200 °C (400 °F) 150 °C (300 °F)		Manufacturer's representative (Ricwil)
)	85 °C (185 °F) 190 °C (370 °F)		Manufacturer's representative (Ricwil)
o it	≈ 150 °C (300 °F)	Maximum exposure temperature is limited by that of electrical conductor insulation.	
r eing o g	None	Method is not recommended for use above Curie point of metal, due to loss of heating efficiency.	Smith (1980), IEEE (in preparation)
e ng nd	None	This type of heating is often used to melt metals and keep them in a molten state.	IEEE (in preparation)

Table 2. Advantages and disadvantages of available heat tracing methods.

	Advantages	Disadvantages
A. Fluids		
1. Heat transfer fluids	Precise temperature control.	
a. Glycols	Can retrofit a steam system to use aqueous glycol solutions. Depresses freezing point of water.	Needs a circulating system.
b. Heat process fluids (organics)	Precise temperature control. Wide temperature range. Low freezing temperatures.	Relatively expensive. Needs a circulating system.
2. Steam	Can take advantage of waste steam. Rugged. No danger of arcing in explosive environments. High heat transfer rates are possible (can provide rapid melt-out). Does not need a reliable electric power source.	Non-uniform distribution of heat. Expensive to install and maintain. Temperature control is not precise. Not always practical above 200°C (400°F) due to high vapor pressures involved.
B. Electricity		
	Precise temperature control. Various temperature control options	Needs a reliable electric power source.
1. Resistance	Relatively inexpensive.	Exposure to high temperatures and/or moisture will damage some insulation and cables.
a. Series	Rugged. Capable of high temperatures.	Cannot be field-cut. One break in the cable causes an open circuit. Will burn out if crossed over itself.
b. Parallel	Can be field-cut. If a resistor fails, heating circuit is still maintained.	Relatively fragile.
1) Continuous and zonal		Will burn out if crossed over itself.
2) Self-limiting	Will not burn out if crossed over itself. Responsive to local heat demands.	Somewhat more expensive than other forms of parallel heat tape.
2. Skin effect	Simple components (i.e. easy to construct and repair). Rugged. Needs relatively few energy inputs. Can be part of prefabricated insulated pipe bundle.	Impractical for applications less than 150 m (500 ft) long.
3. Impedance	High heat transfer rates are possible. Can be easily retrofitted on existing metal pipeline systems. High temperatures are possible. Heating element (pipeline) cannot burn out.	Need to insulate pipe surface in order to avoid electrical hazard to personnel. May need to electrically isolate flanges and pipeline from support structure. Requires specific design for each application.
4. Inductance	High temperatures are possible. High heat transfer rates are possible. Heating element cannot burn out.	Very expensive. Irregularities such as valves and flanges difficult to design for. Requires specific design for each application.



4. The construction of self-limiting electrical resistance heat tape (a) and a diagram of the self-limiting action (in the conductive material) on a molecular level (b) (after Speer and Kucklinca 1975).

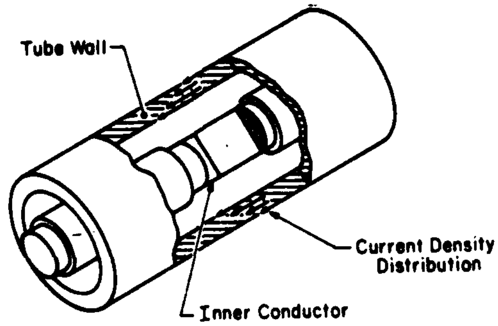
Continuous and zonal parallel heat tape, like series resistance heat tape, varies the temperature by varying the current. Parallel heat tape can burn out if crossed over itself or if exposed to high temperatures along the pipeline.

Self-limiting parallel resistance heat tape consists of two conductors which act as bus wires with a continuous sheet of semi-conductive material between them (see Fig. 4). The material between the conductors consists of graphite particles embedded in a matrix of a cross-linked copolymer. When the temperature of the heat tape increases, the matrix expands, increasing the distance between the conductive graphite particles. This increases the electrical resistance and reduces the amount of heat output at that location. Self-limiting heat tracing thus provides heat only as it is needed. Self-limiting heat tape cannot maintain a temperature above 150°C (300°F) and cannot be exposed to high temperatures without damaging the system (Fenster 1984).

Self-limiting heat tracing can be crossed over itself without the possibility of burn-out; it can respond to local heating demands; it is flexible and can be field-cut. The low likelihood of burn-out makes it inherently safe. But as with any electrical tracing, caution must be exercised to ensure that the control system is safe and that the entire system is installed properly. Self-limiting heat tracing can burn out with a constant current source, but this problem is rare since constant voltage sources are most often used.

Although self-limiting heat tracing is more rugged than other forms of parallel resistance heat tracing, it is less rugged than series resistance heat tracing.

For design of electrical resistance heat tracing see Luke and Miserlis (1977), Stewart (1977), Bylin and Hutzel (1979), Lonsdale (1981), and IEEE (1983).



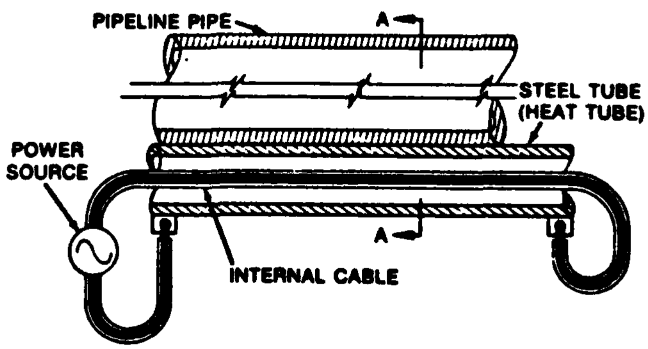
5. Current density distribution due to skin effect (after Burpee and Carson 1977).

Methods based on alternating current effects

Skin Effect Tracing. Skin effect refers to the tendency of alternating current to flow in the outer part of the current-carrying conductor. At power frequencies (60 Hz) in common copper or aluminum conductors, the size and properties of the conductor are such that skin effect is insignificant. If ferromagnetic mild steel is used as a conductor, the skin effect is an order of magnitude greater and becomes significant.

The second inductive effect which is utilized by skin effect tracing is known as the "proximity effect"—the attraction between two opposite-flowing currents located close together. If two conductors are arranged coaxially, and the currents are flowing in opposite directions as with skin effect tracing, the current on the outer cylindrical conductor will be attracted to the inside. Figure 5 illustrates the current density distribution in coaxial conductors with currents flowing in opposite directions.

The direction of current flow in the skin effect circuit is such that the current flows out through a small low-resistance conductor which is located inside of a large cylinder made of ferromagnetic mild steel. The outer cylinder is also the return current path (see Fig. 6). The inner conductor transmits the current with only slight heat generation (I^2R loss). The prox-



6. Cross-sectional view of skin effect heat tracing (modified from Ando and Kawahara 1976).

imity of the inner conductor causes the skin effect current in the outer conductor, or "heat tube," to be concentrated on the interior of its surface. This pronounced skin effect causes a large generation of heat. The system is relatively safe since the current is carried on the interior of the tube (Ando and Kawahara 1976). The tube is attached to the product pipe by intermittent welding or heat transfer cement to provide a thermally conductive path. Very few energy inputs are required along a line—one power station can service up to 48 km (30 miles) of line.

Skin effect current tracing is constructed of ordinary, low-cost materials and can be installed using standard construction techniques. As a result, skin effect tracing is relatively inexpensive to install, very rugged, and easy to repair. The manufacturer will assist with design, and it can be purchased as part of a prefabricated pipe, heat tracer and insulation bundle.

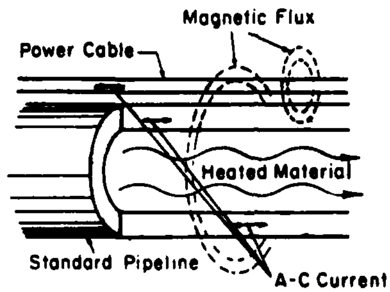
Given a reliable power source, the disadvantages of skin effect tracing are few. The upper temperature limit of just above 150°C (300°F) is set by the maximum exposure temperature of the insulation of the electrical conducting wire located inside the heat tube. Skin effect tracing is not practical or economical to use on lengths of pipeline less than 150 m (500 ft) long. Skin effect tracing's main application is in petroleum product transport on long lines requiring good temperature control. It has also been used to prevent water from freezing in long water mains.

Skin effect was rated by IEEE as having a high system efficiency and high system power factor.* It is described by Ando (its inventor) and Kawahara (1976) and by IEEE (in preparation).

Impedance Heating. Impedance heating is the term applied to a heat tracing system in which an electrical connection is made directly to the (metal) process or carrier pipe. The pipe itself is the heating element and its effective resistance is the source of heat.

The significant benefits of impedance heat tracing are its high temperature capabilities and the fact that because the pipeline is the heating element, it cannot burn out (although

* *Power factor* is the ratio of the actual power consumed in an AC circuit to the product of the RMS (root mean square) voltage and amperes in the circuit. A high power factor is desirable since it allows the power-generating equipment to be operated at optimum efficiency.



7. Current and magnetic flux lines of impedance heating system (after Koester 1978).

the supply cable or connections can). Impedance heating also has high heat transfer rates and uniform heat distribution, leading to exceptionally good temperature control. Simple on/off thermostatic control (utilizing thermocouples) can maintain temperatures within 2°C (3°–4°F). Finer control can be obtained with analog controllers. Another outstanding advantage of impedance heating is that it can be retrofitted to an existing pipeline without disturbing its thermal insulation.

Even though the elements of an impedance heating system are simple, each system needs to be individually engineered to meet the design criteria, and the engineering can become complicated. If a piping system has many branches, electrical balance is hard to obtain. Flanges may require electrical isolation if more than one power source, such as a transformer, is used to obtain electrical balance. The pipeline itself needs to be electrically isolated from its support structure (that is, operated "ungrounded" except at one point). Since currents exist on all external surfaces of the pipeline, they need to be guarded from contact by personnel. Pipelines are normally operated at 30 volts or less as an added precaution.

Impedance heating requires more energy input than skin effect but less than induction heating. IEEE (in preparation) rates both the system efficiency and the system power factor of impedance heating as moderate. The only application of impedance heating found recorded in the literature is viscosity maintenance, as required by the petrochemical industry (Koester 1978, Smith 1980).

IEEE (in preparation) provides a review of the special considerations involved in the design and installation of impedance heating systems.

Induction Heating. Induction heating is the process of creating heat in an electrical conductor by placing it in the magnetic field of an alternating current source. This is accom-

plished by winding a low-resistance wire or series of wires around a conductive pipeline or vessel with high magnetic permeability so that heat is generated without actual electrical contact between the wire and the structure. The coils are connected to an AC voltage source. The alternating current flowing through the coils induces eddy currents and hysteresis losses in the pipeline material. The heat generation associated with these effects is the source of heat.

Aside from very high temperature capabilities, the primary advantage of induction heating is the absence of thermal resistance between the heat tracing and pipeline. The pipeline can therefore be heated quite rapidly. (Incidentally, a primary design consideration is that the coils being used often need to be thermally protected from the pipeline.)

The disadvantage of induction heating is its expense. Each system needs to be specially designed. Power inputs are required at short intervals along the pipeline and material requirements are very large.

Achieving uniform temperature distribution would be a painstaking design process; coil spacing would have to be adjusted for every pipeline irregularity such as a valve or flange. Care would have to be taken to ensure that any uneven heating caused by irregularities in the wall, coil or external flux path was tolerable (Erickson 1984, IEEE in preparation).

Induction heating is not a likely candidate for most heat tracing applications. IEEE (in preparation) rates induction heating as having moderate system efficiency and a low system power factor. Induction heating is most frequently used for melting metals and maintaining them in a molten state. No other mention of its use was found in the literature reviewed. It is reviewed here for its potential in high-temperature applications.

For more information on induction heating, see IEEE (in preparation) and/or any text on induction heating.

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